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What Is The Relationship Between Altitude  
And Weight In A Model Rocket?

Abstract:

This experiment was designed to find a function of payload weight for altitude. The same rocket was launched a repeated number of times with the same engine and varying amounts of weight. After performing experimentation, it was calculated that the altitude in meters could be predicted with the equation  $A=2.8W^2-70.6W+310.3$ , with weight expressed in the unit ounces.

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## Introduction:

Aerodynamics, the science with which this project deals, is the study of the forces acting upon an object as it moves through a fluid, such as air. Most often, aerodynamics is applied to studying heavier-than-air craft, such as airplanes.

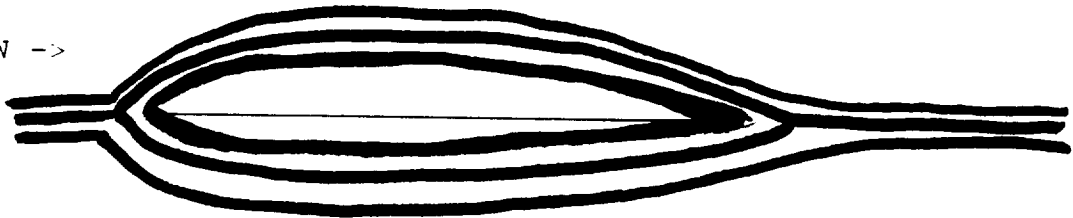
The four main forces acting upon such an object are lift, gravity, thrust and drag. Lift is the force acting on an object perpendicular to its velocity vector. Gravity is the force which pulls an object towards the center of the earth. For a rocket, thrust is the force which propels an object along its velocity vector. Thrust is opposed by drag, the force which slows an object moving through a fluid.

Governing most of the work done in aerodynamics are the laws of motion developed in the seventeenth century by Sir Isaac Newton. Also, his concept of a fluid's resistance to motion, known as viscosity, has an effect on work concerning aerodynamics.

In 1738, Daniel Bernoulli applied Newton's laws of motion to fluids. In his work he formulated what is known as Bernoulli's Law, which states that the sum of the dynamic pressure and the static pressure must always equal a given constant value, without regard to frictional losses. A bit more simply stated, this means that if the outward, or static, pressure of a fluid decreases, the dynamic pressure, or pressure against an object blocking the flow of the fluid, must increase enough that their sum remains the same. This brings us to the main point of Bernoulli's Law, that if a fluid speeds up, some of the static pressure must be traded off to allow for the increase in dynamic pressure.

An airfoil, the cross-sectional shape of an airplane wing, utilizes this in order to achieve flight. An airfoil is shaped like this:

AIRFLOW ->



This shape is used in order to increase the speed of the airflow over the top of the airfoil. When this happens, the air pressure on the underside of the airfoil exceeds the air pressure on the upper side of the airfoil. This creates an imbalance in pressure which is what causes lift.

### Purpose:

The purpose of this experiment was to find a mathematical equation for predicting the altitude that a model rocket will attain with any given weight. More importantly, this experiment outlined a procedure for finding such a relationship for any model rocket.

### Hypothesis:

While conducting background research, no reference to any relationship between altitude and weight in a heavier-than-air craft that accounted for all factors could be found. However, information from Estes Model Rocket Co. contained formulas for predicting altitude which did not account for aerodynamic drag or air resistance, and these formulas showed that qualitatively, a relation between altitude and weight would be parabolic in nature. However, a quantitative hypothesis as to the relationship between altitude and weight could not be made.

### Procedure:

To find a relationship between altitude and payload weight, an Estes Nova Payloader model rocket was launched 6 times with each of 7 different payload weight values. Then, using the average values, an equation was derived to represent the average rocket behavior. The engines used in the rocket have a thrust range between 0.56 and 1.12 Pound-Seconds. For further information on the materials and methods, refer to Appendix 3.

### Results:

For the data collected in the experiment, refer to Appendix 1. These data are displayed in various ways in Appendix 2.

Figure 1 in Appendix 2 shows the average altitude for each of the weights for the first day, the second day, and a combined average. The fourth bar shows an average using only values that fall within 1 standard deviation value. Interestingly, this graph shows that on the first day there was an altitude increase between 3 and 3.5 ounces. Most likely, this is due simply to chance. Figure 2 is very similar, but shows only the values for combined and combined adjusted averages. The discrepancy mentioned about day 1 flights is no longer evident when the values are averaged with values from day 2 flights. Figure 3 is just a simple line graph showing the values for the combined adjusted average. This graph is what first suggested that a relation between altitude and weight would be parabolic in nature. Figure 4 shows both the combined adjusted average and the parabolic curve fit to the combined adjusted average values. Figure 5 shows the combined adjusted average of the flight altitudes and calculated flight altitude using calculations from Estes Model Rocket Co.

### Conclusions:

As I hypothesized, there seemed to be a parabolic relationship between altitude and weight as suggested by Figure 3. Using the data from maximum, medium, and median weights, I was able to find that when launching a Nova Payloader model rocket with a B4-4 engine, the altitude of the rocket can be predicted by the equation  $A=2.8W^2-70.6W+310.3$ , where A is the rocket's altitude in meters and W is the weight of the rocket in ounces. This equation yields about an 11% margin of error. This margin of error can possibly be attributed to experimental error and uncontrollable variables such as weather conditions and engine thrust consistency.